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EDITORIAL

From product and process scale down to finer scales: a new type of multiscale sustainability system

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Engineering sustainability has been extensively studied over the past decades. Tremendous progress has been made in the development of scientific methodologies, engineering approaches, tools, and technologies that help greatly industries to conduct comprehensive sustainability assessment, perform broad and in-depth sustainability performance analysis, develop short-to-long-term sustainable development strategies, and implement them effectively to achieve stage-wise goals. It is evidently shown that companies making sustainability as a goal followed by persistent effort have been achieving competitive advantage. From the systems science and engineering point of view, the known methodologies, approaches, technologies, and tools are mostly for addressing sustainability problems at the scales from product/process up to plant/company, industrial zone, industrial sector in a nation, or even beyond. All together, they can be defined as Type I multiscale sustainability system problems. Spatial-temporally, they address sustainability issues at the scales from around 10^{-1} to 10^{1} m and 10^{-1} to 10^{2} s (for most products and processes) up to 10^{N} meters ($N \geq 6$, for nationwide sector or beyond) and 10^{M} seconds ($M \geq 7$, year or longer). Obviously, continuous efforts on the development of new methodologies and technologies will be needed, particularly in the digital era.

It has been recognized that a variety of sustainability problems appeared in the product manufacturing and use phases may not be fundamentally solved at the process design and operation stages. Taking nanocoating as an example, it can be manufactured using nanopaint, as nanopaint can offer surface coatings very powerful functionalities and attractive properties, such as self-repairing damaged surface area, repelling or neutralizing toxic chemicals, acids, or other corrosive agents, allowing surface texture to be altered at will, and passing or impeding selectively signals to/from wireless devices. It is known that nanocoating performance is largely determined by the type, amount, anisotropic shape, and orientation of nanoparticles (NPs) in nanopaint as well as paint chemistry (Xiao et al. 2010). The assurance of nanocoating quality requires research at the atomistic scale in order to characterize fine physical, chemical, and thermodynamic details; these are critical for generating fundamental insights about the interfacial interaction between NPs and polymer matrix (Uttarwar et al. 2013). In nanopaint application, the mechanism and pathways of the emission of NP-containing paint droplets in air and water should be investigated at the meso scale. In the nanocoating manufacturing stage, coating–curing process design and operational setting at the macroscale should be optimized, based on the type of nanopaint and product quality specifications (Song et al. 2016). Thus, the sustainability issues appeared in the development of nanopaint–nanocoating system suggests a multiscale sustainability type that is from the product/process level, down to the physical, chemical, and interfacial phenomena level, and further down to the molecule or even atom level. We can name it as the Type II multiscale sustainability system. Spatial-temporally, the system addresses sustainability issues from around 10^{-1} to 10^{1} m and 10^{-1} to 10^{2} s (for most products and processes) down to 10^{-s9} m (for molecules or even smaller) and 10^{-9} s (e.g., interaction between NPs and between NPs and polymer matrix). This is apparently very different from the commonly studied Type I sustainability problems, which is from the product/process level up to plant/company and even further to industrial sector or beyond.

There exist a large number of Type II multiscale sustainability problems in industry. This type of problems basically cannot be solved just using conventional methods. The well-known sustainability metrics systems, e.g., the IChemE Sustainability Metrics (Metrics and Institution of Chemical Engineers Sustainable Development Progress Metrics Recommended for Use in the Process Industries. 2002) or

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AIChE sustainability index (Cobb et al. 2009), have been widely adopted in industries. Each of such metrics systems contains sets of indicators for measuring different aspects of economic, environmental, and social sustainability. They are applicable to the performance evaluation of processes and products, and if comparable statistics are gathered from a number of process operations, then they can be aggregated to present a view of a plant or company, and further to the study of sustainability performance of an industrial sector, or an industrial region. If the study involves product life cycle, then LCA is a powerful tool for evaluating environmental impact. There are also various footprint assessment methods for the study of, for example, energy footprint, material footprint, water footprint, carbon footprint, land footprint, etc. However, they are only for the study of Type I, but not Type II multiscale sustainability problems. Thus, there is a clear need for the research community to develop sustainability metrics systems for the assessment and analysis of Type II multiscale sustainability systems. Such a type of metrics systems should include indicators that can measure the potential economic, environmental, and social performance at the meso-to-microscopic levels. The indicators need to be developed by resorting to multiscale system modeling methods that concerns the derivation of equations, parameters, or simulation algorithms that describe system behavior at finer length–time scales (Levitt 2014; Horstemeyer 2009). In addition to the challenges in metrics development, probably more important, challenging tasks are the methodological development for the determination of parameters at the fine scales necessary for metrics evaluation and for aggregating assessment results at the micro and mesoscales, where the accessible data are likely stochastic and uncertain, and for integrating the micro–mesoscale assessment results into the sustainability assessment at the macroscale, which is at the process and product level.

Sustainability performance improvement of the Type II multiscale systems will heavily rely on the decisions to be derived based on the sustainability assessment results at the finer length–time scales. Due to the stochastic nature of the Type II system, decision-making methods will be mostly likely based on stochastic optimization theory (Spall 2003). This is again different from those decision-making methods for the Type I systems, which are mostly deterministic using either linear or nonlinear optimization models (Moradi Aliabadi and Huang 2016). This renders a research need for developing stochastic optimization-based decision-making methodologies for the Type II multiscale sustainability system problems.

Over the past decades, this journal has published numerous papers that introduced very interesting scientific methodologies and reported practical applications to tackle sustainability problems in the Type I multiscale sustainability category. We have also seen publications addressing sustainability issues in the Type II multiscale sustainability system category. It is conceivable that novel sustainability metrics, and sustainability assessment and decision-making methodologies for solving subtle Type II multiscale sustainability problems will appear in this journal in the near future.

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Declarations

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